The Non-Local Scheme in CAM3

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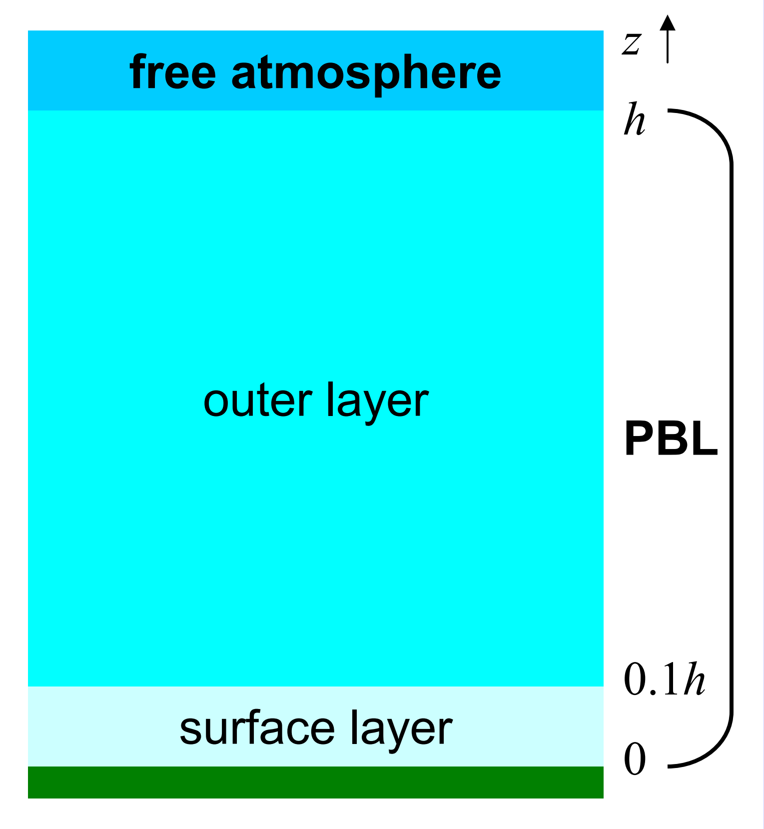
introduction

$$\frac{\partial C}{\partial t} = \cdots + \frac{\partial}{\partial z}\left(\overline{w'C'}\right) + \cdots$$

$$\overline{w'C'} = -K_c\left(\frac{\partial C}{\partial z} - \gamma_c\right)$$



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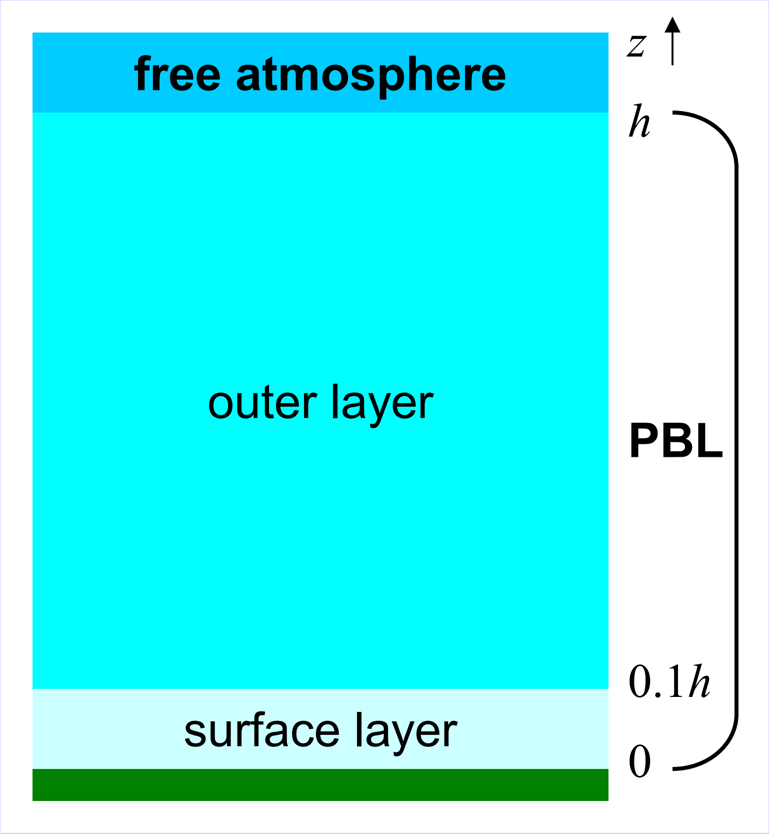
$$K_c \text{ in PBL} = \max\left(K_{\text{PBL}}, K_{\text{free}}\right)$$



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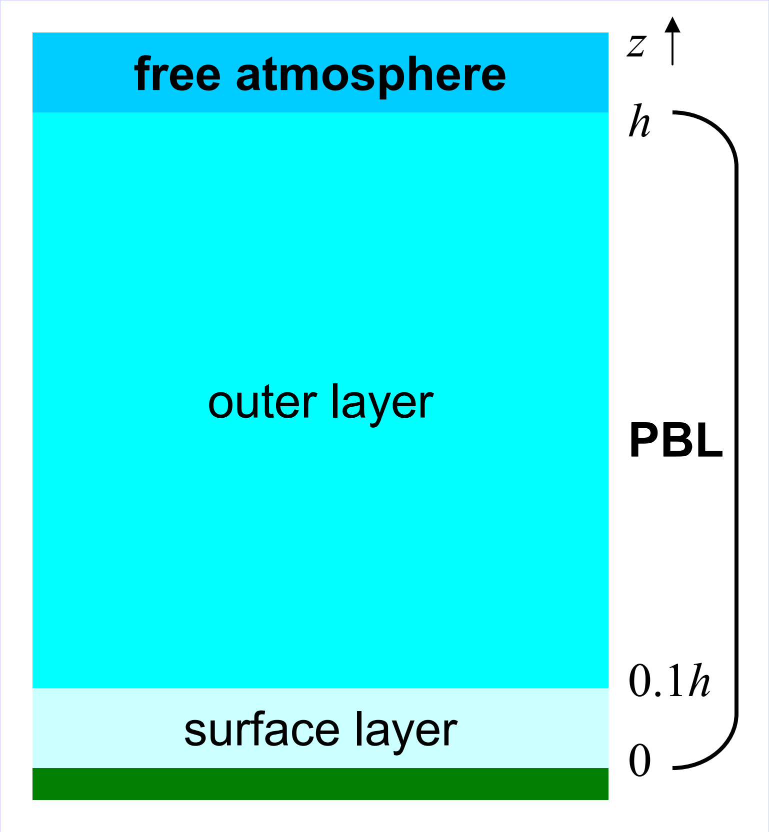

input and output

input parameters	output parameters
potential temperature	kinematic sfc. const. flux
temperature	eddy diffusivities
specific humidity	countergradient terms
height above surface	convective temp. excess
pressure	convective hum. excess
wind speed	surface friction velocity
surface wind stress	Obukhov length
surface SH flux	PBL height
surface constituent flux	

free atmosphere K_c

(Holtslag and Boville 1993)

$$K_c = \ell_c^2 \left| \frac{\partial \mathbf{V}}{\partial z} \right| F_c(Ri)$$

$$F_c(Ri) = (1 - 18Ri)^{1/2}$$

***Ri* < 0**

$$F_c(Ri) = \frac{1}{1 + 10Ri + 80Ri^2}$$

***Ri* > 0**

$$Ri = \frac{g}{\theta_v} \frac{\partial \theta_v / \partial z}{\left| \partial \mathbf{V} / \partial z \right|^2}$$

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C 5 F 2

determination of *h*

$$h = z \text{ where } Ri = Ri_{cr} = 0.3$$

(Vogelezang and Holtslag 1996)

$$Ri = \frac{\frac{g}{\theta_{v_s}}\left[\theta_v(z) - \theta_{v_s}\right]\left[z - z_1\right]}{\left[u(z) - u_1\right]^2 + \left[v(z) - v_1\right]^2 + \beta u_*^2}$$

$$\theta_{v_s} = \theta_{v_1} + b\frac{\left(\overline{w'\theta_v'}\right)_s}{w_m}$$

sensitivity of *h* formulation

		L26	L52	L104	20 m
	Median (m)	-73	14	38	79
Clear	IQR (m)	290	161	128	137
	r	0.48	0.80	0.81	0.79
	Median (m)	-153	-18	12	47
Cloudy	IQR (m)	792	396	326	370
	r	0.06	0.78	0.79	0.76

Zeng et al., 2004: Marine atmospheric boundary layer height over the Eastern Pacific: data analysis and model evaluation. *J. Climate*, **17**, 4159-4170.

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$$\theta_{v_s} = \theta_{v_1} + b\frac{\left(\overline{w'\theta_v'}\right)_s}{w_m}$$

C	F
3	0
8	**2**

determination of K_c

$$K_m = k w_m z \left(1 - \frac{z}{h}\right)^2$$

$$K_{(q,H)} = k w_t z \left(1 - \frac{z}{h}\right)^2$$

determination of K_c

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turbulent velocity scales

$$w_m = \frac{u_*}{\phi_m} \Rightarrow \phi_m = \left(1 - 15\frac{z}{L}\right)^{-1/3} \quad \phi_m = 1 + 5\frac{z}{L} \quad \phi_m = 5 + \frac{z}{L}$$

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$z/L < 0$	$0 \le z/L \le 1$	$z/L > 1$

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$z / L < 0$ | $0 \le z / L \le 1$ | $z / L > 1$

$$w_t = \frac{w_m}{\Pr} \Rightarrow \quad \Pr = \frac{\phi_h(0.1h/L)}{\phi_m(0.1h/L)} + ak\frac{0.1h}{h}\frac{w_*}{w_m}$$

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z / L < 0   ***0 ≤ z / L ≤ 1***   ***z / L > 1***

$$w_t = \frac{w_m}{\Pr} \Rightarrow \Pr = \frac{\phi_h(0.1h/L)}{\phi_m(0.1h/L)} + ak\frac{0.1h}{h}\frac{w_*}{w_m}$$

C	F
8	0
16	**2**

turbulent velocity scales

$$w_m = \frac{u_*}{\phi_m} \Rightarrow \phi_m = \left(1 - 15\frac{z}{L}\right)^{-1/3} \quad \phi_m = 1 + 5\frac{z}{L} \quad \phi_m = 5 + \frac{z}{L}$$

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$z / L < 0$ **$0 \le z / L \le 1$** **$z / L > 1$**

$$w_t = \frac{w_m}{\mathrm{Pr}} \Rightarrow \mathrm{Pr} = \frac{\phi_h(0.1h/L)}{\phi_m(0.1h/L)} + ak\frac{0.1h}{h}\frac{w_*}{w_m}$$

C	F
8	6
16	8

countergradient term

$$\gamma_c = a \frac{w_* \left(\overline{w'C'} \right)_s}{w_m^2 h}$$

$$w_* = \left(\frac{g}{\theta_{vs}} \left(\overline{w'\theta_v'} \right)_s h \right)^{1/3}$$

countergradient term

$$\gamma_c = a \frac{w_* \left(\overline{w'C'}\right)_s}{w_m^2 h}$$

$$w_* = \left(\frac{g}{\theta_{vs}} \left(\overline{w'\theta_v'}\right)_s h \right)^{1/3}$$

C	F
1	0
17	**8**

scheme sensitivity

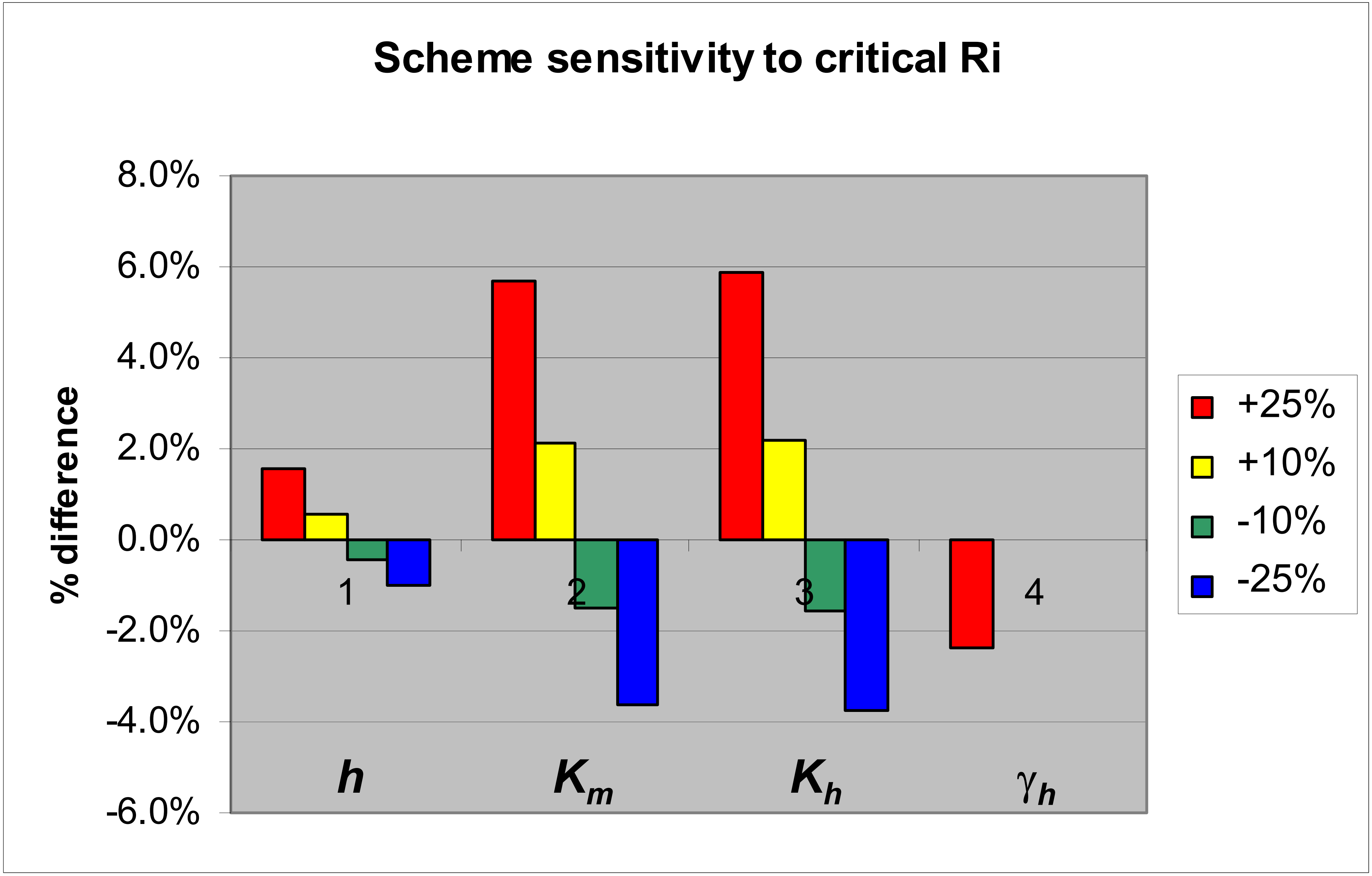
Tested sensitivity to choices for:

- Ri_{cr}
- β
- b
- a

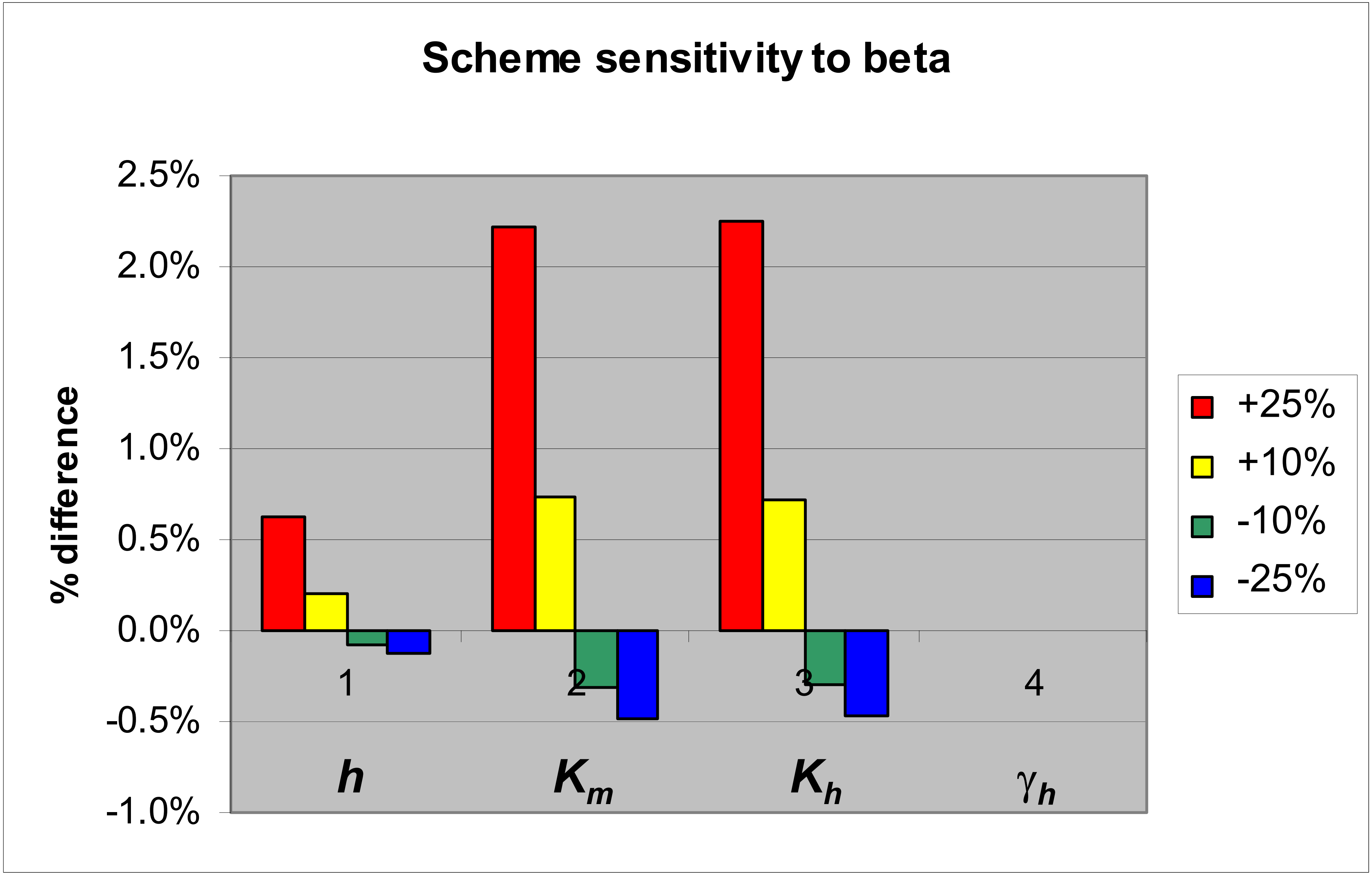
$$Ri = \frac{\frac{g}{\theta_{v_s}}\left[\theta_v(z) - \theta_{v_s}\right]\left[z - z_1\right]}{\left[u(z) - u_1\right]^2 + \left[v(z) - v_1\right]^2 + \beta u_*^2}$$

$$\theta_{v_s} = \theta_{v_1} + b\frac{\left(\overline{w'\theta_v'}\right)_s}{w_m}$$

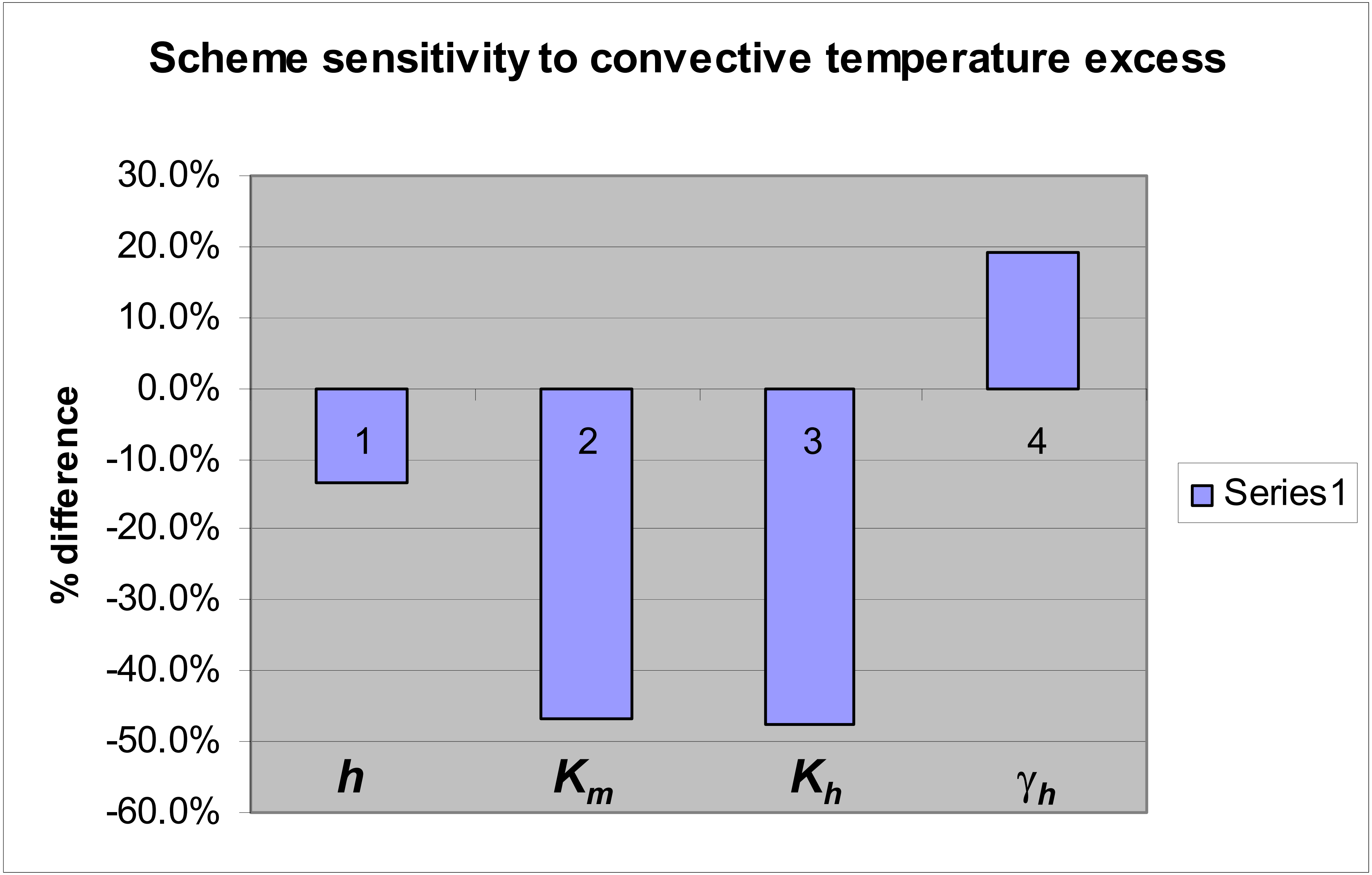
$$\gamma_c = a\frac{w_*\left(\overline{w'C'}\right)_s}{w_m^2 h}$$



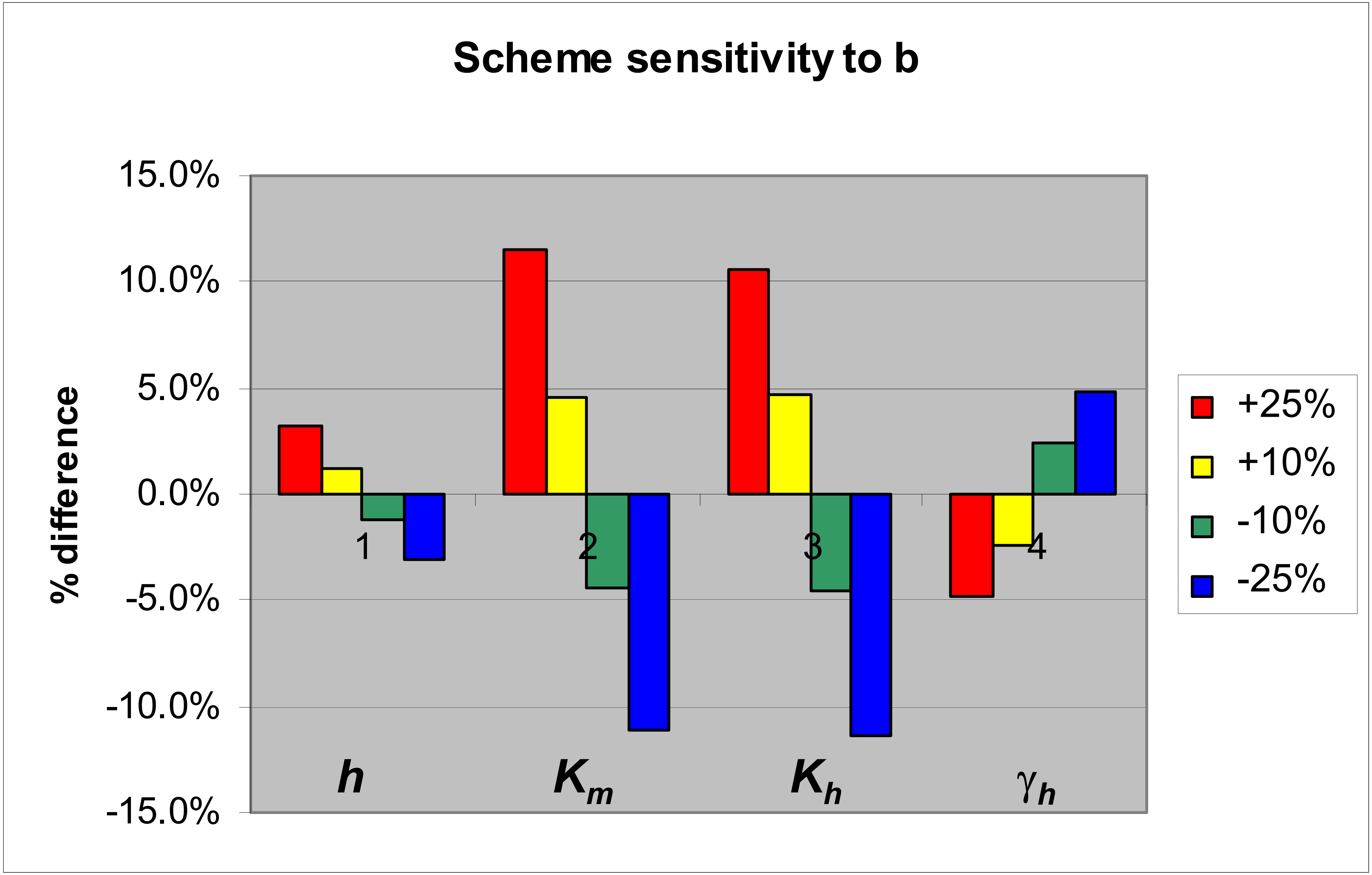
Scheme sensitivity to critical Ri
% difference
8.0%
6.0%
4.0%
2.0%
0.0%
-2.0%
-4.0%
-6.0%
1
2
3
4
h
K_m
K_h
γ_h
+25%
+10%
-10%
-25%

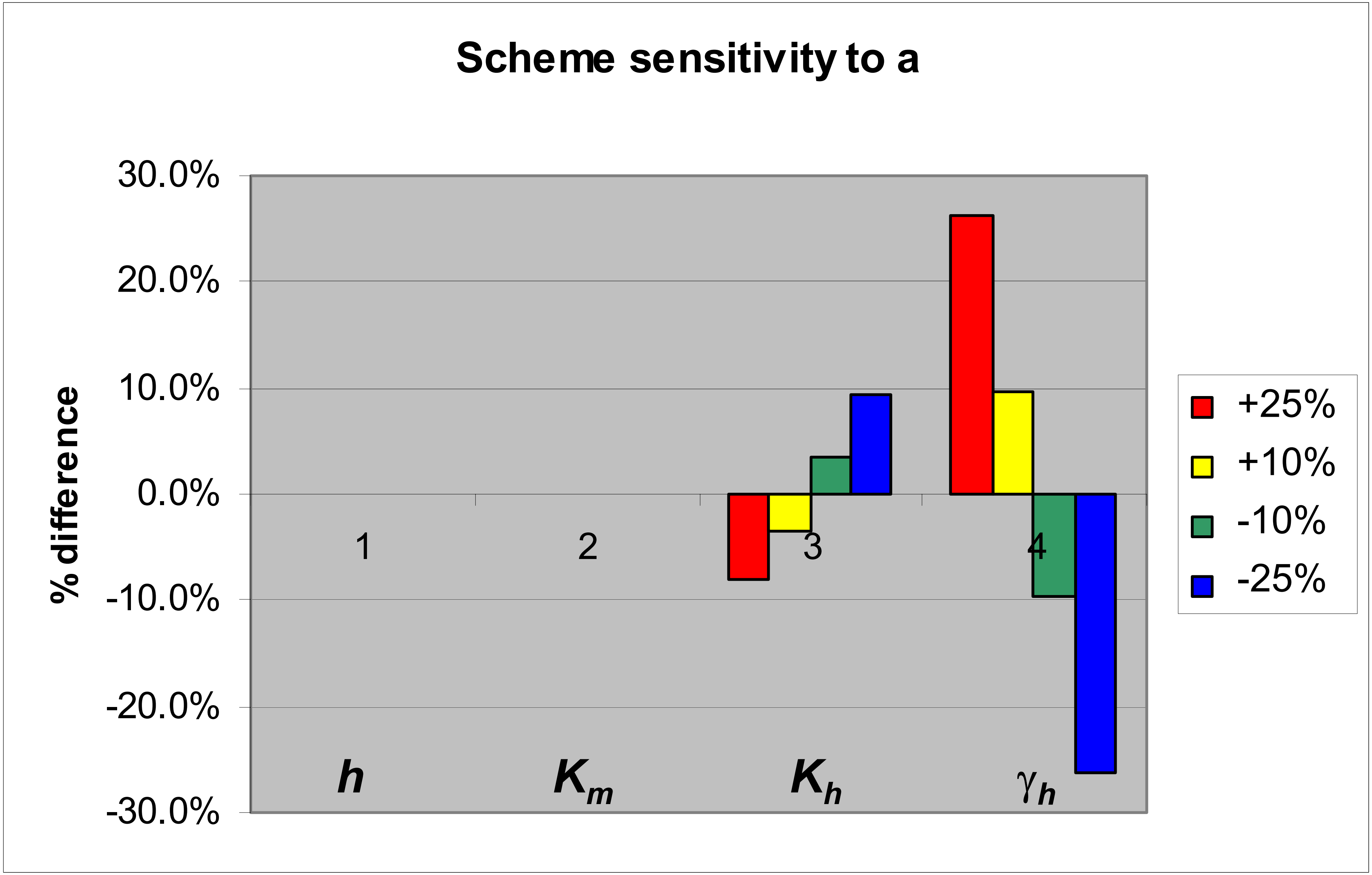


Scheme sensitivity to beta
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
-0.5%
-1.0%
% difference
1
2
3
4
h
K_m
K_h
γ_h
+25%
+10%
-10%
-25%



Scheme sensitivity to convective temperature excess
% difference
30.0%
20.0%
10.0%
0.0%
-10.0%
-20.0%
-30.0%
-40.0%
-50.0%
-60.0%
1
2
3
4
h
Km
Kh
γh
Series1


Scheme sensitivity to b
15.0%
10.0%
5.0%
0.0%
-5.0%
-10.0%
-15.0%
% difference
1
2
3
4
h
Km
Kh
γh
+25%
+10%
-10%
-25%



Scheme sensitivity to a
30.0%
20.0%
10.0%
0.0%
-10.0%
-20.0%
-30.0%
% difference
1
2
3
4
h
Km
Kh
γh
+25%
+10%
-10%
-25%

look-up table?

- Not much value added by a LUT.
  - Simple formulation
  - Module runs very quickly.
- Pull *h*’s from a LUT?
  - Model run to get LUT values could be run at L31.

summary

- CAM3 uses standard non-local turbulence scheme in PBL.
- 17 tunable constants and 8 arbitrary functions.
- Scheme not sensitive to Ri_{cr} and β; are sensitive to b and a
- Convective temperature excess is needed.
- LUT probably not necessary except maybe to get *h*.